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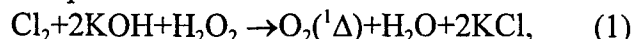
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### 1.Introduction.

The singlet oxygen generator is the source of energy in chemical oxygen-iodine laser (COIL). Efficiency of COIL operation depends on ratio  $[H_2O]/[O_2]$ . For lower this ratio COIL operation is more efficient. Thus the COIL operation will be better with increasing of oxygen pressure in SOG and decreasing of BHP temperature. High output oxygen pressure allows to realize different kinds of mixing schemes of iodine with  $O_2(^1\Delta)$ . Jet type singlet oxygen generator (JSOG) is a high pressure source of oxygen with high  $O_2(^1\Delta)$  yield. It is possible to generate oxygen at 80 torr with  $O_2(^1\Delta)$  yield 60% and  $Cl_2$  utilization more than 90% [1]. The volume between JSOG and iodine mixer can be made with minimal volume. In this case  $O_2(^1\Delta)$  transport losses will be minimal. The best COIL scaleable configuration is realized when cross section of JSOG is equal to cross section of laser cavity (Verty-JSOG-COIL configuration). In this case the specific power ( $wt/cm^2$ ) directly depends on specific chlorine flow rate in JSOG ( $mmole/cm^2/s$ ). The JSOG provides the highest specific chlorine flow rate ( $>10 mmole/cm^2/s$ ) up to now [1]. The specific power more than  $317 wt/cm^2$  can be achieved in COIL having 35% chemical efficiency.

The reaction between gaseous  $Cl_2$  and basic hydrogen peroxide solution is used for  $O_2(^1\Delta)$  generation. Several types of base can be used: KOH, NaOH, LiOH .... or mixtures of these bases. In the case of using pure KOH the initial KOH- $H_2O_2$ - $H_2O$  solution is homogeneous down to  $-30C$ . During COIL operation BHP is depleted:



The depleted chemicals are KOH and  $H_2O_2$ , generated chemicals are KCl,  $H_2O$ . The first step of  $O_2(^1\Delta)$  generation in BHP is reaction between  $Cl_2$  and  $HO_2^-$ . In the first approximation  $HO_2^-$  concentration is proportional to KOH concentration in BHP. The dissolved salt KCl can generate insoluble KCl crystals. The solubility of KCl depends on BHP temperature. Thus the depleted BHP solution can change efficiency of  $Cl_2$  utilization and  $O_2(^1\Delta)$  generation. It is important to know how COIL power depends on BHP depletion and BHP temperature. These dates are important for estimation of maximum extractable energy from BHP without adding KOH and  $H_2O_2$  to BHP during COIL operation.

The purposes of the experiments are the next:

1. Optimization of gas-flow conditions in the existing supersonic COIL+JSOG at BHP composition 8M=KOH, 9M= $H_2O_2$  ( $H_2O_2$ -KOH=1M), 0M=KCl, temperature  $-20^\circ C$ . Measurements of the power dependence on mirror transmission (saturation curve) at the optimal gas flow conditions.
2. Optimization iodine flow rate and pressure inside JSOG for BHP:  
 $H_2O_2$ =9M, KOH=8M, KCl=0M,  $t=-10C$ ,  $0C$   
 $H_2O_2$ =8M, KOH=6M, KCl=2M,  $t=-20C$ ,  $-10C$ ,  $0C$   
 $H_2O_2$ =7M, KOH=4M, KCl=4M,  $t=-20C$ ,  $-10C$ ,  $0C$
3. Dependence of the COIL power on mirror transmission at the optimal flow conditions.
3. Measurements of  $O_2(^1\Delta)$  yield,  $Cl_2$  utilization and  $H_2O$  concentration in front of the supersonic nozzle.

## 2. The description of existing supersonic COIL driven by Jet type singlet oxygen generator (JSOG)

### Specifications:

$P_1$ —pressure in reaction zone of JSOG

$P_2$ —pressure in intermediate chamber

$P_3$ — pressure in laser cavity

$P_4$  —pressure in Pito tube

$P_5$ —pressure in vessel with gaseous chlorine

$P_6$ —pressure in iodine absorption-spectroscopy tube

$P_7$ —pressure in chlorine absorption-spectroscopy tube (pressures in torr)

$P_{H_2O}$ —water vapor pressure in the intermediate chamber

$(P_{H_2O})_s$ —saturated water vapor pressure

$P_{\Delta-O_2(^1\Delta)}$  pressure in the intermediate chamber

$M_C$ (mmole/s) = chlorine molar flow rate through Jet SOG

$M_I$ (mmole/s)—iodine molar flow rate through iodine mixer

$M_{NS}$ (mmole/s) —secondary nitrogen molar flow rate through iodine mixer

$M_{NP}$ (mmole/s)—primary nitrogen molar flow rate through nitrogen mixer

$T_1$ (%)—output mirror transmission (the value specified by manufacturer)

$T_2$ (%)— second mirror transmission (the value specified by manufacturer)

$T_1 + T_2$ (%)—total mirror transmission

$W_1$ (watt)—measured output power from mirror with  $T_1$

$W_t$ (watt) =  $W_1 \cdot (T_1 + T_2) / T_1$ —assumed total power

$W_{10}$ (watt)(normalized power) =  $W_t \cdot 10 / M_C$ —assumed total power for 10 mmole/s of chlorine

$\eta_{chem}(\%) = W_t / 0.906 / M_C$ —total chemical efficiency of COIL

### The COIL set-up in Samara consists of following main sub-systems:

BHP preparing and delivering system: JSOG+SCOIL, iodine generator, vacuum system, gas feeding system. The main units of set-up are (Fig.1):

1-tank for preparing of BHP solution, 2-tank for receiving of BHP from JSOG, 3-JSOG, 4 – intermediate chamber with injector of buffer gas, 5- iodine injector, 6- supersonic nozzle, 7- laser cavity with mirrors. The detail drawings with dimensions of this parts were presented in report1.

The tank 1 is made from polyethylene (volume 20 liters) and equipped with heat exchanger, mixer. The BHP is delivered into JSOG through two polyethylene tubes 10 mm i.d. Each polyethylene tube is equipped with EM-valve for fast switch on-off BHP flow. The tank 2 has double jacket. Outer tank is made from polyethylene, inner tank is made from stainless steel (15 liters).

JSOG is made from Plexiglas. The reaction between the surface of BHP jets and chlorine occurs in reaction chamber. The BHP jets are generated through cylindrical nozzles made in 3 mm thickness plate. The standard JSOG+COIL test is made with nozzle grid having 106 nozzles 0.8 mm in diameter. These parameters give specific surface 4.7 calculated in the approximation of jets like rods. The row of nozzles closer to slit valve have 20 mm length (stainless steel tubes) so that its ends were lower than slit valve. Other nozzles 0.8 mm in diameter were drilled in plate. The BHP from tank 1 is delivered to jet nozzles (Fig.1) by atmospheric pressure. The chlorine is injected into reaction chamber through two perforated

stainless steel tubes (8 mm outer diameter, 6 mm inner diameter) mounted into the walls of chamber 100 mm apart from slit valve. Each tube has 22 holes 1 mm in diameter uniformly distributed on the length 46 mm. The generated  $O_2(^1\Delta)$  flows out of chamber through slit valve (choke). The turn of slit valve allows to change the cross

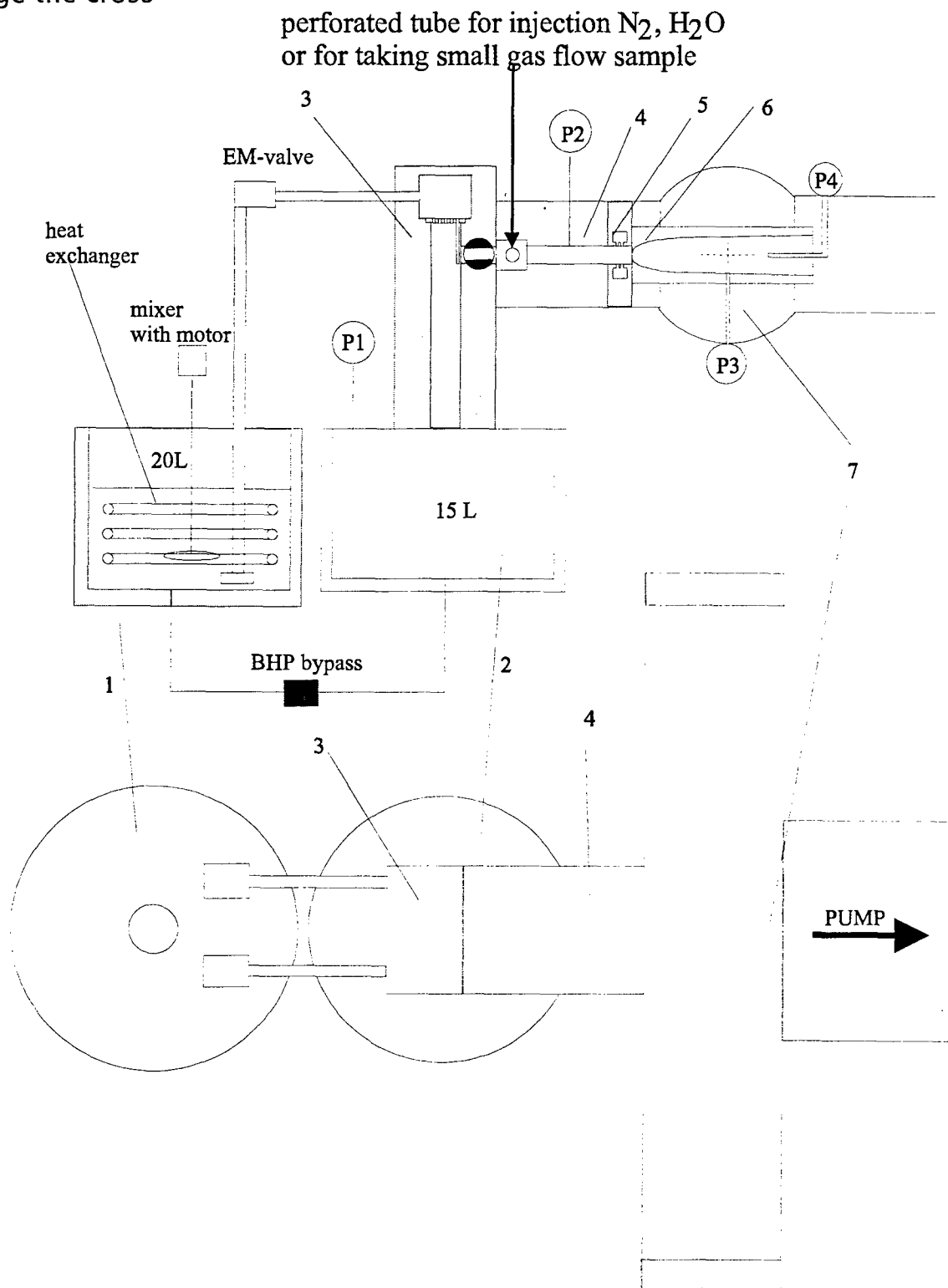


Fig.1.  
section of the slit to vary gas pressure and volumetric gas velocity in reaction chamber.

The intermediate chamber 4 is made from Plexiglas and insists for mixing of buffer gas with oxygen. The  $N_2$  gas is delivered to perforated nickel tube installed as close as possible to slit valve of JSOG. The  $N_2$  gas is injected through two rows of holes  $\varnothing 0.5$  mm in diameter uniformly drilled in nickel tube (thickness of nickel tube walls 0.25 mm). The axis of holes directed  $45^\circ$  relative to axis of intermediate chamber.

The iodine injector 5 is made from copper. The  $I_2+N_2$  gas mixture is injected into  $O_2+N_2$  flow through two rows of nozzles in each wall of injector. Each row of nozzles has 21 holes  $\varnothing 0.6$  mm. The iodine injector body is heated with water (60C) to avoid iodine condensation.

The supersonic nozzle 6 is made from Plexiglas. The profile of nozzle was calculated by method of characteristics for specific heat ratio 1.4. The walls of nozzle were turned  $2^\circ$  to compensate partially boundary layer effect. The calculated profile is presented in Table.

Table of nozzle profile.

X	0	3.9	4.8	5.5	6.4	7.5	8.2	8.9	9.5	9.8	10.5	11.1
Y	4	5.0	5.3	5.5	5.7	6	6.1	6.2	6.3	6.4	6.5	6.6

X	11.8	12.5	13.2	14.	15	16.	17.7	19	39.9	55.9	80
Y	6.7	6.8	6.9	7.	7.1	7.2	7.3	7.35	8.	8.7	9.3

The distance between throat of nozzle and the closest row of holes of iodine injector is 3 mm, the distance between optical axis and throat of nozzle is 55 mm. Laser cavity 7 is made from polyamide plastic. The supersonic nozzle is installed inside laser cavity. The flow width is 50 mm at inlet of laser cavity and 60 mm at the outlet of laser cavity. The mirror aperture along gas flow is 45 mm. The distance between mirrors is 630 mm.

Iodine vapors are generated in Teflon chamber by heating of solid iodine by light of halogen lamp (600 W). The chamber is cylinder 150 mm i.d. 50 mm in height. The preheated carrier gas  $N_2$  is introduced into Teflon chamber through perforated stainless steel tube. After that iodine flows into measuring tube, where  $I_2$  concentration is measured by absorption spectroscopy method. From absorption tube iodine flows into iodine injector. Iodine pathway is heated up to 60C.

The vacuum receiver tank (4000 L) is used to provide high volumetric pump of gas flow in laser cavity. This vacuum receiver tank is pumped with oil mechanical pump 125 L/s. Liquid  $N_2$  trap is installed before oil pump to trap iodine, chlorine, water vapor. The simultaneous operation of oil pump and receiver (initial pressure in vacuum receiver tank 0.1 torr) provides pump rate > 500 L/s during 5 sec for  $O_2:N_2=1:3$  gas mixture.

The chlorine is delivered into JSOG from steel vessel (40L) where gaseous chlorine is kept at pressure  $\approx 1$  atm.

The buffer gas feeds iodine generator, purge of mirrors, intermediate chamber where  $O_2$  is mixed with  $N_2$ (He,Ar).

### 3. Measurements

#### 3.1. Description of methods.

General. The pressures  $P_1, P_2, P_3, P_4$ , pressure  $P_5$  in vessel with gaseous  $\text{Cl}_2$ , pressure  $P_6$  in iodine,  $P_7$  in chlorine absorption spectroscopy tubes were measured with error  $\pm 1\%$ . BHP temperature was measured with accuracy  $\pm 0.1^\circ\text{C}$ .

BHP molarity. The total molarity of KOH was defined by standard acid-base titration. The total molarity of  $\text{H}_2\text{O}_2$  ( $\text{H}_2\text{O}_2 + \text{HO}_2^-$ ) was defined after adding  $\text{H}_2\text{SO}_4$  acid to BHP. The redox titration using  $\text{KMnO}_4$  yielding total peroxide content. The main error of titration is due to bubbles of oxygen in small sample (0.1 ml) of BHP. The estimated error of titration is 5%.

COIL power. 8% of output radiation from mirror with highest transparency  $T_1$  was directed and focused on sensitive element of standard power meter LPM-905 (Fig.2). The error of measurements of power was 5%.

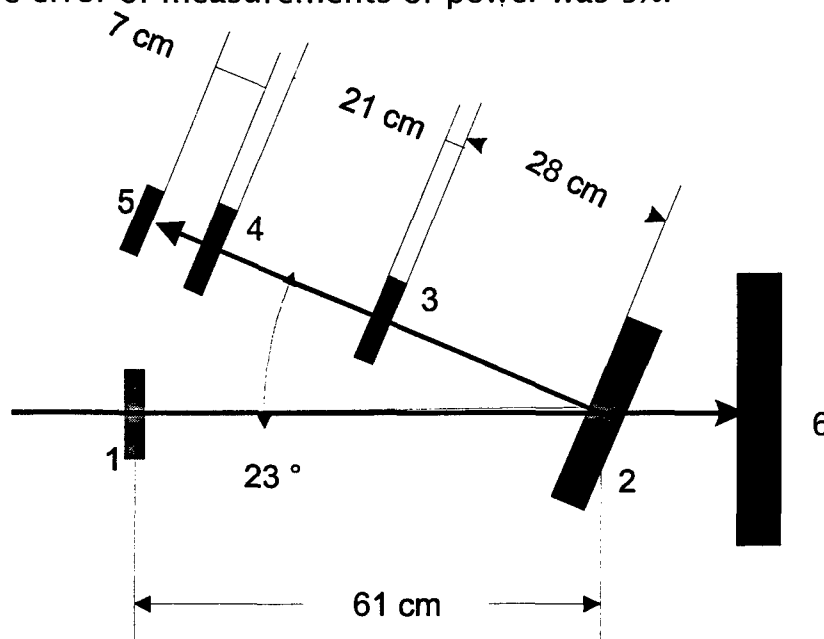


Fig.2.

1-output mirror with transmission  $T_1$ , 2-parallel glass plate, 3-30 cm focus lens, 4-7.5 cm focus lens, 5-sensitive element of power meter, 6-nielloed wood surface. This lens configuration provides laser beam size on sensitive element less than size of sensitive element (10 mm in diameter). Maximum beam size on output mirror was  $45 \times 17 \text{ mm}^2$ . The reflection from parallel glass plate 8%, the transmission of each lens 92% were assumed. The power measured by sensitive element is  $W_m = 0.92 \times 0.92 \times 0.08 W_1 = 0.0677 W_1$ , where  $W_1$ —the laser power from output mirror. The output power  $W_1 = 14.77 W_m$ .

Gases flow rates. The chlorine molar flow rate was defined as

$$M_c = \frac{(P_5(f) - P_5(i))V_c}{(t_f - t_i)RT}, \text{ where } P_5(f), P_5(i) \text{—chlorine pressure in vessel with gaseous}$$

chlorine before and after COIL running, the volume of vessel  $V_c = 40$  liters,  $(t_f - t_i)$  is time interval of switch-on position of electromagnetic valve on vessel,  $R = 8.31 \text{ J/mole/K}$ —universal gas constant,  $T$ —vessel temperature (usually 298K). The pressure  $P_5(f)$  was measured 5 min later switching-off valve to avoid error as a result of adiabatic cooling of chlorine in vessel. Usually the initial chlorine pressure equaled to 800 torr and final pressure was not less than 750 torr (10 s

COIL run). The error 10% of method is due mainly to error of measurements of pressure and time interval ( $t_f - t_i$ ).

The iodine molar flow rate was measured by absorption spectroscopy method. The light beam from the white-light stable lamp propagates through tube with length  $L_{12} = 10$  cm and 2 cm in diameter and directed to monochromator. The iodine+nitrogen gas from iodine vapor source axially flows through this tube. The light attenuation at 500 nm is detected with Si-photodetector. The iodine molar flow rate was calculated as

$$M_{I_2} = \frac{\ln\left(\frac{I_0}{I}\right)}{L_{12}\sigma_{I_2}} \left( \frac{RTM_{N_2}}{P_6} \right),$$
 where  $I_0$ ,  $I$  - Si-detector output without and with iodine in nitrogen flow,  $L_{12} = 10$  cm absorption length,  $\sigma_{I_2} = 2.1 \times 10^{-18}$  cm<sup>2</sup> cross section of iodine absorption at 500 nm [2],  $P_6$  nitrogen pressure in absorption tube.

Nitrogen (secondary and primary) molar flow rates were measured and fixed with standard mechanical flow meters.

For measurements of water vapor content and  $O_2(^1\Delta)$  yield the measuring cell was installed between intermediate chamber 4 and nozzle. The iodine injector was removed (see Fig.3).

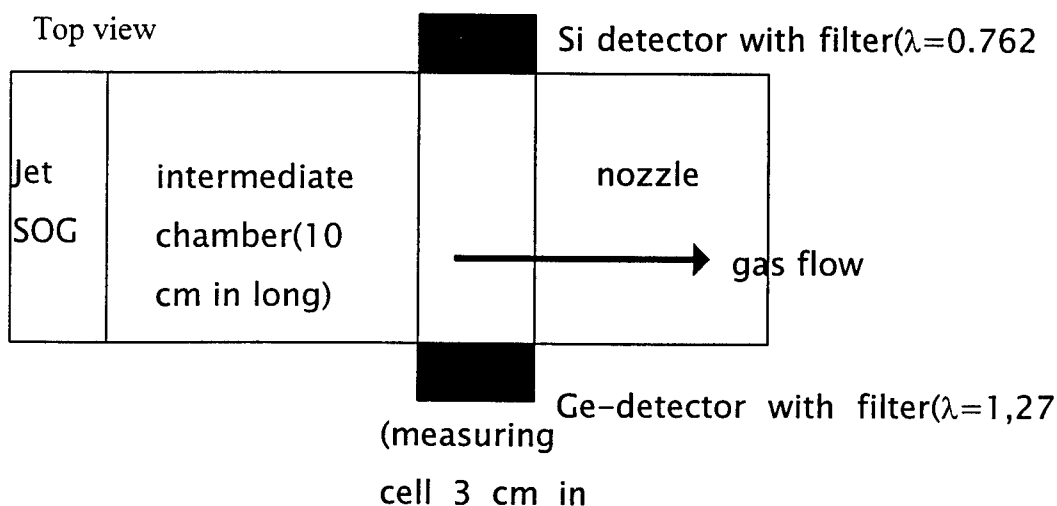


Fig.3.

For measurements of  $Cl_2$ ,  $H_2O$  and  $O_2(^1\Delta)$  the pure chlorine was delivered into JSOG. The gas «velocity-pressure» conditions inside JSOG were the same as in the case of laser operation. But primary and secondary nitrogen was not mixed to gas flow.

The water vapor was defined as  $P_{H_2O} = C(U_{1270})^2/U_{762}$ , where  $C = 0.027$  (torr/volt) - calibrated coefficient,  $U_{1270}$  (volt) - output from Ge-detector + amplifier,  $U_{762}$  (volt) - output from Si-detector + amplifier. The  $O_2(^1\Delta)$  partial pressure (or molar flow rate) from JSOG was defined as  $P_\Delta = AU_{1270}$ , where  $A = 1.23$  torr/volt - calibrated coefficient.

A small amount of the gas flow from intermediate chamber is directed into absorption -spectroscopy tube (50 cm long) to measure residual chlorine. For this purpose a small amount of gas flow was pumped through perforated tube which used earlier for adding nitrogen. For detection of residual chlorine in gas flow we

used absorption spectroscopy method at  $\lambda=337$  nm (nitrogen laser). The chlorine utilization was defined as  $U=1-P_c/P_7$ , where  $P_c$ -is chlorine partial pressure in absorption tube,  $P_7$ -is pressure inside absorption tube minus partial water vapor in absorption tube. The partial chlorine pressure inside absorption tube was

defined as  $P_c = \frac{\ln\left(\frac{I_{p1} I_{r2}}{I_{r1} I_{p2}}\right)}{L_c \sigma_c} (RT)$ , where  $\frac{I_{p1}}{I_{r1}}$  and  $\frac{I_{p2}}{I_{r2}}$  the ratio of probe and reference

beam without and with chlorine in tube accordingly,  $L_c=50$  cm absorption length,  $\sigma_c=2.45 \times 10^{-19}$  cm<sup>2</sup> -absorption cross section,  $T=298$ K -assumed gas temperature in absorption -spectroscopy tube. The sensitivity of method was approximately 0.02 torr of residual chlorine. The minimal detectable percentage of residual chlorine was 2% at 1 torr of total pressure in absorption - spectroscopy tube.

The outputs from all measuring units were connected with data acquisition and PC.

### 3.2. Calibration of water vapor measurement.

The main quencher of  $O_2(^1\Sigma)$  in  $O_2 + H_2O$  mixture is water molecules. The concentration of  $O_2(^1\Sigma)$  is proportional to concentration of  $O_2(^1\Delta)$  squared and reverse proportional to  $H_2O$ . The output from Si- detector + amplifier is proportional to the spontaneous emission at 762 nm or to concentration of  $O_2(^1\Sigma)$ . :

$$U_{762} = C_1 [O_2(^1\Delta)]^2 / [H_2O]$$

The output from Ge-detector +amplifier is proportional to the intensity of spontaneous emission at 1270 nm or to concentration of  $O_2(^1\Delta)$ :

$$U_{1270} = C_2 [O_2(^1\Delta)]$$

The water vapor concentration is equal to  $[H_2O] = C(U_{1270})^2 / U_{762}$ ,  $C = (C_2)^2 / C_1$  ( $C_1$ -constants). If one adds known amount of water vapor  $[H_2O]_0$  during JSOG run the next equation takes place:

$$[H_2O]_0 = C \{ (U_{1270})^2 / U_{762} \}_1 - C \{ (U_{1270})^2 / U_{762} \}_0 ,$$

where  $\{ (U_{1270})^2 / U_{762} \}_0$  and  $\{ (U_{1270})^2 / U_{762} \}_1$  are ratios of outputs before and after adding of known amount of water vapor partial pressure to gas flow from JSOG. It will be possible to calibrate coefficient  $C$  if one knows  $[H_2O]_0$ . In fig 4 one example of JSOG run with adding of fixed amount of partial water vapor pressure is presented.  $P_2$ (in photo cell) is the pressure in measuring cell. The active JSOG operation starts at 5th second. The adding of water vapor through perforated tube starts at 13th sec. A small decreasing of Ge-detector with adding of water we explain with increasing of sonic velocity in throat of nozzle that results in dropping of partial  $O_2(^1\Delta)$  pressure.

$P_2$



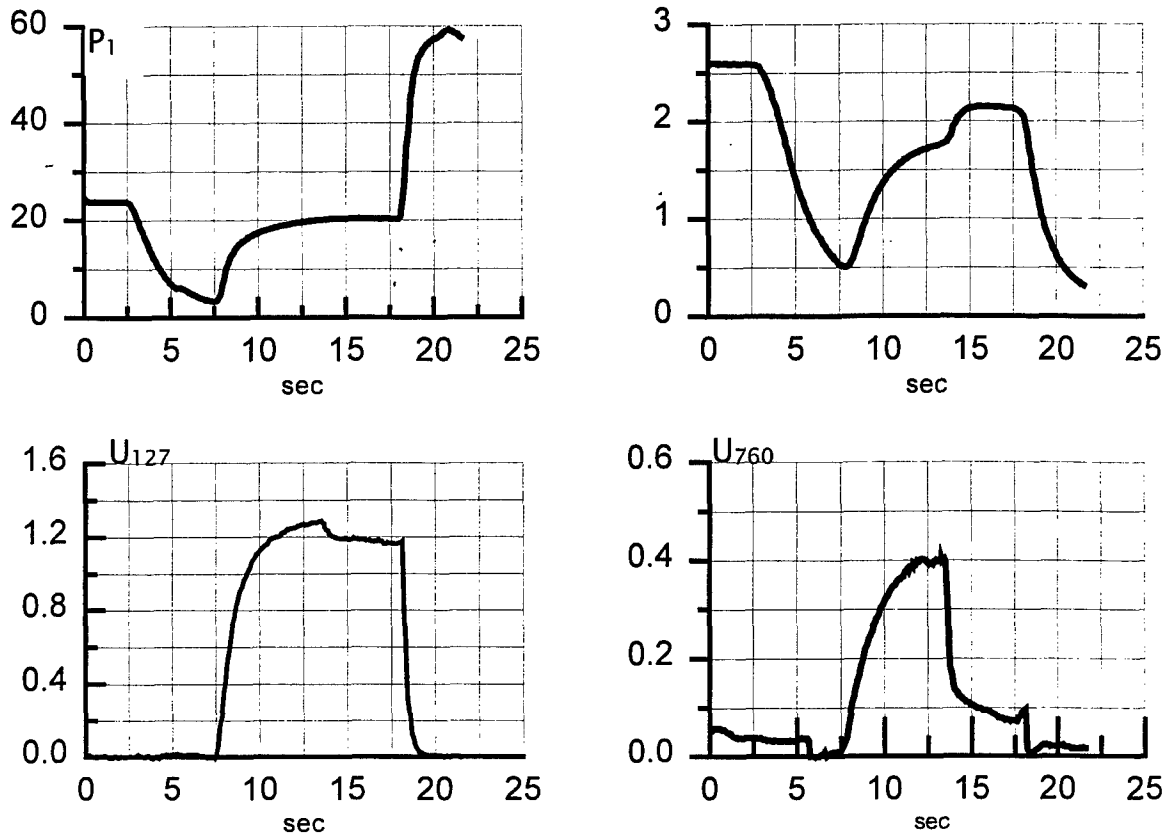


Fig.4

In Table the results of calibration are presented.

Before adding water vapor				after adding water vapor				H <sub>2</sub> O	C(10 <sup>-3</sup> )
U <sub>1270</sub> , Volt	U <sub>762</sub> , Volt	(U <sub>1270</sub> ) <sup>2</sup> /U <sub>762</sub> Volt	(P <sub>2</sub> ) <sub>i</sub> ,	U <sub>1270</sub>	U <sub>762</sub>	(U <sub>1270</sub> ) <sup>2</sup> /U <sub>762</sub>	(P <sub>2</sub> ) <sub>f</sub> ,	P <sub>H2O</sub>	torr/volt
1.16	0.41	3.28	1.54	1.1	0.137	8.83	1.39	0.15	27
1.06	0.43	2.61	1.53	0.97	0.098	9.6	1.53	0.2	28.6
1.27	0.58	2.761	1.764	1.13	0.088	14.5	2.07	0.3	25.7
1.28	0.4	4.09	1.78	1.19	0.079	17.9	2.14	0.35	25.3

$P_{H2O} = (P_2)_f - (P_2)_i$  - added water vapor partial pressure. The average value of calibration coefficient  $C = 0.0267$  torr/volt. In JSOG experiments the water vapor partial pressure was calculated as

$$P_{H2O} = 0.027 \times \{(U_{1270})^2 / U_{762}\}.$$

### 3.3. Calibration of $O_2(^1\Delta)$ measurements.

The calibration procedure is based on assumption that at low partial chlorine pressures in reaction zone of JSOG and short flight time of gas through JSOG reaction zone and intermediate chamber the  $O_2(^1\Delta)$  yield close to 94%. This result was obtained with error appr. 10%. 3

The calibration procedure consists of measurements of Ge-detector output when JSOG operates at low partial chlorine pressure. The JSOG operated at total pressure  $\approx 20$  torr and initial chlorine pressure  $\approx 2$  torr (mixture  $N_2:Cl_2=9:1$ ) in reaction zone. BHP temperature was  $-17^\circ C$ . The residual chlorine at the exit of JSOG was not detected. The linear gas velocity inside reaction zone was 13 m/s and in intermediate chamber 170 m/s. The gas flight time from chlorine injector to measuring cell  $10/1300+10/17000=8.3$  ms. The results of measurements of pressures and Ge-output presented in Table:

$P_1$	$U_{Ge}, V$	$P_2, \text{torr}$	$P_o, \text{torr}$	$A(\text{torr/V})$
21	0.19	2.5	2.3	1.15
17.1	0.151	2	1.8	1.13
25	0.22	3.2	3	1.28
22	0.22	3.0	2.8	1.2
22	0.19	2.6	2.4	1.2
22.5	0.188	2.9	2.7	1.35
20	0.163	2.4	2.2	1.29

$P_2$ – the total pressure in measuring cell,  $P_o = (P_t - P_{H_2O})/10$ –partial oxygen pressure in intermediate chamber,  $A = P_o \cdot 0.94 / U_{ge}$ .  $P_{H_2O} = (P_{H_2O})_s / P_{SOG} \cdot P_t$ , where  $(P_{H_2O})_s = 1.4$  torr is water vapor pressure inside reaction zone at  $-17^\circ C$  (p.6.1).

The average value of calibrated coefficient  $A = 1.23$  Torr/volt and standard deviation 8%. The total error of measurements of  $O_2(^1\Delta)$  concentration approximately  $15 \div 18\%$ .

### 3.4. Measurements of residual $Cl_2$ .

The cross section of chlorine absorption at  $\lambda = 337$  nm was obtained by standard routine. The absorption spectroscopy tube 50 cm in length was filled with chlorine and attenuation of light at 337 nm was measured. The attenuation of light was proportional to chlorine pressure in tube. The cross section  $\sigma_{Cl_2} = 2.45 \times 10^{-19} \text{ cm}^2$  was obtained. This value slightly differ from value in [2]. The noise to signal ratio allowed to detect minimal partial chlorine pressure 0.02 torr.

## 4. Test of supersonic COIL with Jet Type SOG at different BHP compositions and temperatures.

The supersonic COIL driven with Jet-SOG operates at chlorine flow rates up to 25 mmole/s. But 10 mmole/s of chlorine flow rate was delivered to JSOG for parametric experiments. Preliminary it was found that the optimal operational pressure inside JSOG was  $20 \div 23$  torr at 10 mmole/s of chlorine flow rate for all BHP compositions and temperatures. The calculated average gas velocity inside

JSOG was approximately 14 m/s. BHP flow rate was 220 ml/s( $\pm 5\%$ ) for all compositions and temperatures. It means that BHP pressure losses mainly are due to acceleration and expansion of liquid flow in pipes and valves rather than with viscosity of BHP. The average BHP velocity inside nozzle was  $4 \div 4.4$  m/s.

The order of COIL switch-on and off:

On initial condition-JSOG and COIL are under pump of mechanical pump 125 l/s, vacuum receiver is closed, slit valve of JSOG is opened, iodine generator is closed

deliver approximately 1 mmole/s of nitrogen to blow each mirror

deliver primary 20 mmole/s of nitrogen into intermediate chamber

deliver iodine generator is switched on and secondary nitrogen flow into iodine generator

switch-on BHP line

switch-on 3 sec later the chlorine line and open 4 m<sup>3</sup> vacuum receiver

Off

close chlorine line, iodine line and vacuum receiver

close the slit valve of JSOG

close BHP line

stop deliver primary nitrogen

The pressure  $P_1$  was depended on slit valve position in JSOG and in present experiments at 10 mmole/s of chlorine flow rate was close to 20 torr. At these conditions the pressure  $P_2$  in intermediate chamber depended on iodine flow rate and secondary nitrogen flow rate. At optimal secondary nitrogen flow rate 11.5 mmole/s  $P_2$  depended on iodine flow rate: for higher iodine flow rate  $P_2$  was higher, but not more than 12 torr in present experiments. In the absence of iodine  $P_2$  was equal to 10 torr. At optimal iodine flow rate  $\approx 0.3$  mmole/s the pressure  $P_2$  was equal to  $\approx 11$  torr. At constant chlorine and nitrogen flow rates (primary and secondary) the pressure in laser cavity  $P_3$  and Pito tube  $P_4$  also depended on iodine flow rate. For higher iodine flow rates  $P_3$  and  $P_4$  were higher. The ratio  $P_4/P_3$  allowed to estimate Mach number of gas flow. At iodine flow rate  $\approx 0.3$  mmole/s  $P_3 = 1.8 \div 2$  torr,  $P_4 = 6.8 \div 7.5$  and estimated Mach number was equal to  $1.55 \div 1.65$ .

#### 4.1 Experiments with BHP molarity 8M and temperature $-20^\circ\text{C}$ . (Series 8-20-N2, 8-20-I2, 8-20-TR).

These three series were made during one experimental day. The BHP was prepared from 3650 ml of 33%wt.H<sub>2</sub>O<sub>2</sub> (type 1) and 3150 g of 87% KOH. The titration of BHP resulted in concentrations  $[\text{KOH}] = 8.1\text{M}$ ,  $[\text{H}_2\text{O}_2](\text{total}) = 9.15\text{M}$ . After 4 hours of experiments (series 8-20-N2, 8-20-I2, 8-20-TR) titration resulted in  $[\text{KOH}] = 7.5\text{M}$ ,  $[\text{H}_2\text{O}_2] = 8\text{M}$ . The measured KOH depletion was in agreement with double amount of chlorine moles passed through JSOG. But H<sub>2</sub>O<sub>2</sub> depletion was much higher than it followed from reaction  $\text{Cl}_2 + 2\text{KOH} + \text{H}_2\text{O}_2 \rightarrow \text{O}_2(^1\Delta) + \text{H}_2\text{O} + 2\text{KCl}$ . We explain this depletion with spontaneous H<sub>2</sub>O<sub>2</sub> decomposition.

The results of optimization of secondary nitrogen flow rate are presented in Table-1

Table 1. Series-8-20-N2. Power dependence on secondary nitrogen molar flow rate. Mirror transmission  $T_1=0.8\%$ ,  $T_2=0.18\%$ .

$P_1$	$M_C$	$M_{NS}$	$M_I$	$W_1$	$W_{10}$	$\eta_{chem,}$
18.3	9.3	5.6	0.3	82	107	11.8
21.7	9.7	8.6	0.31	93	117	13
21.5	10.2	10.8	0.3	102	123	13.5
22.6	10.7	13.8	0.31	103	118	13.
21.6	10.3	16.7	0.31	102	121	13.4

The optimal secondary nitrogen molar flow rate 11.5 mmole/s was found. This optimal penetration was used in all other COIL experiments.

The measurements of COIL power at optimal secondary nitrogen flow rate are presented in Table2.

Table 2. Series-8-20-12. Power dependence on iodine flow rate.

$P_1$	$M_C$	$M_I$	$T_1, \%$	$T_2, \%$	$T_1+T_2$	$W_1$	$W_t$	$W_{10}$	$\eta_{chem}$
21.3	10	0.26	0.8	0.18	0.98	97	119	119	13.1
20.8	9.4	0.2	0.8	0.18	0.98	36	44	47	5.18
21.2	9.8	0.34	0.8	0.18	0.98	126	154	158	17.4
20.2	9.9	0.3	0.8	0.18	0.98	120	147	149	16.4
20.9	10.45	0.4	0.8	0.18	0.98	128	157	150	16.6

The optimal iodine molar flow rate was found to be equal 0.35 mmole/s.

The measurements of COIL power at optimal gas flows are presented in Table 3 (saturation curve).

Table 3. Series-8-20-TR. Power dependence on total mirror transmission at optimal iodine flow rate.

$P_1$	$M_C$	$M_I$	$T_1, \%$	$T_2, \%$	$T_1+T_2$	$W_1$	$W_t$	$W_{10}$	$\eta_{chem,}$
21.2	9.8	0.34	0.8	0.18	0.98	126	154	158	17.4
21.2	10.2	0.355	1.7	0.18	1.88	81	90	88	9.7
20.9	10	0.357	0.7	0.18	0.88	98	123	123	13.6
22.1	10.2	0.354	0.8	0.18	0.98	105	129	126	13.9
20	9.9	0.353	0.8	0.8	1.6	41	82	83	9.2
20.9	10.8	0.354	1.7	0.8	2.5	48	71	65	7.2
20.7	10.7	0.356	1.7	1.7	3.4	7.5	15	14	1.55
23.6	10.4	0.351	0.8	0.8	1.6	48	96	92	10.2
21.3	10.4	0.357	0.2	0.09	0.29	62	90	86	9.5
21	9.8	0.351	0.8	0.7	1.5	74	139	142	15.7

22.1	11.1	0.357	0.7	0.8	1.5	59	126.4	113.9	12.57
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These results will be used for estimation of non resonant radiation losses and small signal gain.

#### 4.2. Experiments with BHP molarity 8M and temperature $-10^{\circ}\text{C}$ .(series 8-10-I2, 8-10-TR,).

These two series were made during one experimental day. The BHP was prepared from 3650 ml of 33%wt.  $\text{H}_2\text{O}_2$  (type 1) and 3150g of 87% KOH. The titration of BHP resulted in concentrations  $[\text{KOH}]=8\text{M}$ ,  $[\text{H}_2\text{O}_2](\text{total})=9.05\text{M}$ . After 4 hours of experiments (series 8-10-I2, 8-10-TR) titration resulted in  $[\text{KOH}]=7.3\text{ M}$ ,  $[\text{H}_2\text{O}_2]=8.05\text{M}$ . Results of two series are presented in Tables 4,5.

Table 4. Series-8-10-I2.Power dependence on iodine flow rate.

$P_1$	$M_c$	$M_i$	$T_1, \%$	$T_2, \%$	$T_1+T_2$	$W_1$	$W_t$	$W_{10}$	$\eta_{\text{chem}}$
21.7	10.1	0.2	0.8	0.18	0.98	0.4	0.49	0.48	0.05
22.9	10.3	0.25 4	0.8	0.18	0.98	60	74	71	7.8
20	9.4	0.31	0.8	0.18	0.98	105	129	137	15.1
22	10.3	0.26 5	0.8	0.18	0.98	99	121	118	13
21	9.3	0.35 8	0.8	0.18	0.98	112	137	148	16.3
22.6	10.5	0.40 6	0.8	0.18	0.98	120	147	140	15.4

It was found that optimal iodine flow rate was  $\approx 0.35\text{ mmole/s}$

Table 5. Series-8-10-TR. Power dependence on total mirror transmission at optimal iodine flow rate.

$P_1$	$M_c$	$M_i$	$T_1, \%$	$T_2, \%$	$T_1+T_2$	$W_1$	$W_t$	$W_{10}$	$\eta_{\text{chem}}$
21	9.3	0.35 8	0.8	0.18	0.98	112	137	148	16.3
21.2	10.1	0.35 2	1.7	0.18	1.88	89	98	97	10.7
21.5	9.9	0.35 3	0.7	0.18	0.88	90	113	114	12.6
20.5	10.1	0.35 2	0.8	0.7	1.5	72	135	134	14.7
21.7	10.7	0.35	1.7	0.8	2.5	41	60	56	6.2

		1							
21.7	10	0.35	1.7	1.7	3.4	8.3	17	17	1.8
		2							

### 4.3. Experiments with BHP molarity 8M and temperature $-0^{\circ}\text{C}$ .(series 8-00-I2, 8-00-TR).

These two series were made during one experimental day. The BHP was prepared from 3650 ml of 33%wt.  $\text{H}_2\text{O}_2$  (type 1) and 3150g of 87% KOH. The titration of BHP resulted in concentrations  $[\text{KOH}]=8.17\text{M}$ ,  $[\text{H}_2\text{O}_2](\text{total})=8.92\text{M}$ . After 4 hours of experiments (series 8-00-I2, 8-00-TR) titration resulted in  $[\text{KOH}]=7.6\text{ M}$ ,  $[\text{H}_2\text{O}_2]=7.7\text{M}$ . Results of these series are presented in Tables 6 and Table 7.

Table 6. Series-8-00-I2. Power dependence on iodine flow rate.

$P_1$	$M_C$	$M_I$	$T_1, \%$	$T_2, \%$	$T_1+T_2$	$W_1$	$W_t$	$W_{10}$	$\eta_{\text{chem}}$
21.6	10	0.25	0.8	0.18	0.98	20	24	24.5	2.7
24.9	11	0.3	0.8	0.18	0.98	92	113	102	11.3
24.9	9.5	0.35 3	0.8	0.18	0.98	79	97	102	11.2
24.5	10.2	0.41	0.8	0.18	0.98	89	109	107	11.8
23	10.1	0.45	0.8	0.18	0.98	96	118	116	12.8
22.2	10.3	0.41	0.8	0.18	0.98	80	98	95	10.5
20.3	9.5	0.35	0.8	0.18	0.98	93	114	120	13.2

The optimal iodine molar flow rate was found to be equal 0.35 mmole/s.

Table 7. Series-8-00-TR. Power dependence on total mirror transmission at optimal iodine flow rate.

$P_1$	$M_C$	$M_I$	$T_1, \%$	$T_2, \%$	$T_1+T_2$	$W_1$	$W_t$	$W_{10}$	$\eta_{\text{chem}}$
20.3	9.5	0.35	0.8	0.18	0.98	93	114	120	13.2
20.2	9.3	0.35 5	1.7	0.18	1.88	47	52	56	6.2
21.6	10.2	0.35	0.7	0.18	0.88	93	117	115	12.6
21.6	10.4	0.35 4	0.7	0.8	1.5	41	88	85	9.3
22.3	10.6	0.35 4	1.7	0.8	2.5	36	53	50	5.5
21.6	9.9	0.35	1.7	1.7	3.4	1	2	2.	0.22
21.2	9.9	0.35 7	1.7	0.18	1.88	53	59	59	6.5



#### 4.4. Experiments with BHP molarity 6M and temperature $-20^{\circ}\text{C}$ .(series 6-20-I2, 6-20-TR).

These two series were made during one experimental day. The BHP was prepared from 4000 ml of 35%wt.  $\text{H}_2\text{O}_2$  (type 1), 2220g of 87% dry KOH, 420g of distilled  $\text{H}_2\text{O}$ , 900g of 99.2% wt.KCl. First of all 420 g of water was added to 35%wt. $\text{H}_2\text{O}_2$ . After that dry KCl was dissolved in  $\text{H}_2\text{O}_2\text{-H}_2\text{O}$  at temperature more than  $0^{\circ}\text{C}$ . Then dry KOH was added to solution  $\text{H}_2\text{O}_2 + \text{H}_2\text{O} + \text{KCl}$ . During adding of KOH the temperature of solution was  $0^{\circ}\text{C} \div -7^{\circ}\text{C}$ . Then BHP was cooled to  $-20^{\circ}\text{C}$  and filtered from KCl particles through  $0.3 \times 0.3$  mm filter. The total weight of wet salt was 450 g. But after that BHP contained suspension of salt nevertheless. Thus thermodynamic equilibrium between small salt particles and dissolved KCl took place or BHP was saturated completely with salt. The titration of BHP resulted in concentrations  $[\text{KOH}] = 5.8\text{M}$ ,  $[\text{H}_2\text{O}_2](\text{total}) = 7.6\text{M}$ . After 4 hours of experiments (series 6-20-I2, 6-20-TR) titration resulted in  $[\text{KOH}] = 5\text{M}$ ,  $[\text{H}_2\text{O}_2] = 6.7\text{M}$ . Results of these series are presented in Tables 8 and Table 9.

Table 8. Series-6-20-I2. Power dependence on iodine flow rate.

$P_1$	$M_c$	$M_I$	$T_1, \%$	$T_2, \%$	$T_1 + T_2$	$W_1$	$W_t$	$W_{10}$	$\eta_{\text{chem,}}$
17.6	7.5	0.20 4	0.8	0.18	0.98	0.6	0.74	0.98	0.11
21.7	10.6	0.20 7	0.8	0.18	0.98	50	61	58	6.37
21.7	10.7	0.30 6	0.8	0.18	0.98	129	158	148	16.3
21.8	10.4	0.25	0.8	0.18	0.98	106	130	125	13.8
21.4	10.9	0.35	0.8	0.18	0.98	105	129	118	13.
22.3	10.3	0.3	0.8	0.18	0.98	119	146	141	15.6
21	9.8	0.4	0.8	0.18	0.98	90	110	112	12.4

The optimal iodine molar flow rate was found to be equal 0.30 mmole/s.

Table 9. Series-6-20-TR. Power dependence on total mirror transmission at optimal iodine flow rate.

$P_1$	$M_c$	$M_I$	$T_1, \%$	$T_2, \%$	$T_1 + T_2$	$W_1$	$W_t$	$W_{10}$	$\eta_{\text{chem,}}$
21.4	10.7	0.30 2	1.7	0.18	1.88	125	138	129	14.3

21.7	10.7	0.30 6	0.8	0.18	0.98	129	158	148	16.3
22.1	10.8	0.30 6	0.7	0.18	0.88	124	156	144	15.9
21	10.4	0.31 1	0.7	0.8	1.5	58	124	120	13.2
20.8	9.7	0.30 7	1.7	0.8	2.5	52	76.5	79	8.7
22.8	10.6	0.30 8	1.7	1.7	3.4	25	50	47	5.2
20.7	10.3	0.30 1	0.8	0.7	1.5	63	118	115	12.7
22.3	10.3	0.3	0.8	0.18	0.98	119	146	142	15.6

#### 4.5. Experiments with BHP molarity 6M and temperature $-10^{\circ}\text{C}$ . (series 6-10-I2, 6-10-TR).

These two series were made during one experimental day. The BHP was prepared from 4140 ml of 35%wt.  $\text{H}_2\text{O}_2$  (type 1), 2378g of 87% dry KOH, 694g of distilled  $\text{H}_2\text{O}$ , 900g of 99.2% wt.KCl. First of all 694 g of water was added to 35%wt. $\text{H}_2\text{O}_2$ . After that dry KCl was dissolved in  $\text{H}_2\text{O}_2\text{-H}_2\text{O}$  at temperature more than  $0^{\circ}\text{C}$ . Then dry KOH was added to solution  $\text{H}_2\text{O}_2 + \text{H}_2\text{O} + \text{KCl}$ . During adding of KOH the temperature of solution was  $0^{\circ}\text{C} \div -7^{\circ}\text{C}$ . Then BHP was cooled to  $-10^{\circ}\text{C}$  and filtered from KCl particles through  $0.3 \times 0.3$  mm filter. The total weight of wet salt was 236 g. But after that BHP contained suspension of salt nevertheless. The titration of BHP resulted in concentrations  $[\text{KOH}] = 5.8\text{M}$ ,  $[\text{H}_2\text{O}_2](\text{total}) = 7.5\text{M}$ . After 4 hours of experiments (series 6-10-I2, 6-10-TR) titration resulted in  $[\text{KOH}] = 5.63\text{ M}$ ,  $[\text{H}_2\text{O}_2] = 6.7\text{ M}$ . Results of these series are presented in Tables 10 and Table 11.

Table 10. Series-6-10-I2. Power dependence on iodine flow rate.

$P_1$	$M_c$	$M_i$	$T_1, \%$	$T_2, \%$	$T_1 + T_2$	$W_1$	$W_t$	$W_{10}$	$\eta_{\text{chem,}}$
22	9.3	0.2	0.8	0.18	0.98	45	55	59	6.5
22	9.1	0.25	0.8	0.18	0.98	86	105	116	12.8
21.6	9.3	0.3	0.8	0.18	0.98	111	136	146	16.1
21.4	9.5	0.35	0.8	0.18	0.98	100	122. 5	129	14.2
21.9	9.8	0.4	0.8	0.18	0.98	95	116	119	13.1

The optimal iodine molar flow rate was found to be equal 0.30 mmole/s.

Table 11. Series-6-10-TR. Power dependence on total mirror transmission at optimal iodine flow rate.

$P_1$	$M_c$	$M_i$	$T_1, \%$	$T_2, \%$	$T_1 + T_2$	$W_1$	$W_t$	$W_{10}$	$\eta_{\text{chem,}}$
21.6	9.3	0.3	0.8	0.18	0.98	111	136	146	16.1
22.8	10	0.3	0.7	0.18	0.88	111	140	139. 5	15.4
20.9	9.8	0.3	1.7	0.18	1.88	90	100	102	11.2
21.8	9.2	0.31	1.7	0.18	1.88	81	90	97	10.7
20.7	9.2	0.31	1.7	0.8	2.5	39	57	62	6.9

20.4	8.5	0.3	0.7	0.8	1.5	41	88	103	11.4
23.7	10.2	0.3	0.7	0.8	1.5	56	120	118	13
23.8	10.8	0.3	1.7	1.7	3.4	19	38	35	3.9

#### 4.6. Experiments with BHP molarity 6M and temperature $-0^{\circ}\text{C}$ .(series 6-00-12, 6-00-TR).

These two series were made during one experimental day. The BHP was prepared from 4140 ml of 35%wt.  $\text{H}_2\text{O}_2$  (type 1), 2378g of 87% dry KOH, 694g of distilled  $\text{H}_2\text{O}$ , 900g of 99.2% wt.KCl. First of all 694 g of water was added to 35%wt. $\text{H}_2\text{O}_2$ . After that dry KCl was dissolved in  $\text{H}_2\text{O}_2\text{-H}_2\text{O}$  at temperature more than  $0^{\circ}\text{C}$ . Then dry KOH was added to solution  $\text{H}_2\text{O}_2 + \text{H}_2\text{O} + \text{KCl}$ . During adding of KOH the temperature of solution was  $0^{\circ}\text{C} \div +3^{\circ}\text{C}$ . Then BHP temperature was fixed at  $+1 \div -1^{\circ}\text{C}$  and filtered from KCl particles through  $0.3 \times 0.3$  mm filter. The total weight of wet salt was 100 g. But after that BHP contained suspension of salt nevertheless. The titration of BHP resulted in concentrations  $[\text{KOH}] = 5.9\text{M}$ ,  $[\text{H}_2\text{O}_2](\text{total}) = 7.3\text{M}$ . After 4 hours of experiments (series 6-00-12, 6-00-TR) titration resulted in  $[\text{KOH}] = 5.7\text{M}$ ,  $[\text{H}_2\text{O}_2] = 6.8\text{M}$ . Results of these series are presented in Tables 12 and Table 13.

Table 12. Series-6-00-12. Power dependence on iodine flow rate.

$P_1$	$M_C$	$M_I$	$T_1, \%$	$T_2, \%$	$T_1 + T_2$	$W_1$	$W_t$	$W_{10}$	$\eta_{\text{chem}}$
25.9	10.8	0.20	0.8	0.18	0.98	59	72	66	7.4
	5	7							
24.5	10.5	0.25	0.8	0.18	0.98	100	122.	116	12.8
	7	9					5		
24.7	9.88	0.30	0.8	0.18	0.98	98	120	121.	13.4
		4						5	
23.9	10.3	0.35	0.8	0.18	0.98	87	107	103	11.3
	8	4							
21.1	10.1	0.30	0.8	0.18	0.98	92	113	112	12.3
		9							

The optimal iodine molar flow rate was found to be equal 0.30 mmole/s

Table 12. Series-6-00-TR. Power dependence on total mirror transmission at optimal iodine flow rate.

$P_1$	$M_C$	$M_I$	$T_1, \%$	$T_2, \%$	$T_1 + T_2$	$W_1$	$W_t$	$W_{10}$	$\eta_{\text{chem}}$
24.7	9.88	0.30	0.8	0.18	0.98	98	120	121.	13.4
		4						5	
21.1	10.1	0.30	0.8	0.18	0.98	92	113	112	12.3

		9							
23.3	10.3	0.30	1.7	0.18	1.88	83	92	89	9.8
	4	1							
24.8	10.3	0.30	0.7	0.18	0.88	104	131	126	13.9
	8	4							
22.9	9.54	0.30	0.7	0.8	1.5	44	94	99	10.9
		8							
23.6	9.8	0.29	1.7	0.8	2.5	30	44	45	5
		9							
23	10	0.30	1.7	1.7	3.4	0.5	1	1	0.1
		2							

4.7. Experiments with BHP molarity 4M and temperature  $-17^{\circ}\text{C}$ . (series 4-17-12, 4-17-TR) (The values of power presented in series Tables 14, 15 differ from values presented in report 3. A more accurate processing of dates was made).

These two series were made during one experimental day. The BHP was prepared from 2480 ml of 50%wt.  $\text{H}_2\text{O}_2$  (type 2), 1650g of 87% dry KOH, 2120g of distilled  $\text{H}_2\text{O}$ , 1800g of 99.2%wt. KCl. First of all 2120 g of water was added to 50%wt.  $\text{H}_2\text{O}_2$ . After that dry KCl was dissolved in  $\text{H}_2\text{O}_2\text{-H}_2\text{O}$  at temperature more than  $0^{\circ}\text{C}$ . Then dry KOH was added to solution  $\text{H}_2\text{O}_2 + \text{H}_2\text{O} + \text{KCl}$ . During adding of KOH the temperature of solution was  $0^{\circ}\text{C} \div -7^{\circ}\text{C}$ . Then BHP was cooled to  $-17^{\circ}\text{C}$  and filtered from KCl particles through  $0.3 \times 0.3$  mm filter. The total weight of removed wet salt was 1700 g. But after that BHP contained suspension of salt nevertheless. The titration of BHP resulted in concentrations  $[\text{KOH}] = 4.15$  M,  $[\text{H}_2\text{O}_2]_{\text{(total)}} = 7.02$  M. After 4 hours of experiments (series 4-17-12, 4-17-TR) titration resulted in  $[\text{KOH}] = 3.65$  M,  $[\text{H}_2\text{O}_2] = 6.3$  M. The attempt to cool BHP to  $-20^{\circ}\text{C}$  resulted in ice formation in solution. Results of these series are presented in Tables 14 and Table 15.

Table 14. Series-4-17-12. Power dependence on iodine flow rate.

$P_1$	$M_C$	$M_I$	$T_1, \%$	$T_2, \%$	$T_1 + T_2$	$W_1$	$W_t$	$W_{10}$	$\eta_{\text{chem,}}$
19	9.4	0.20 7	0.8	0.18	0.98	69	85	90	10
21.1	10.2	0.25 4	0.8	0.18	0.98	111	136	133	14.7
19	9.9	0.3	0.8	0.18	0.98	106	129	131	14.4
19.4	9.4	0.28 5	0.8	0.18	0.98	114	140	149	16.4
19.3	10	0.35	0.8	0.18	0.98	100	123	123	13.6

The optimal iodine molar flow rate was found to be equal 0.28 mmole/s

Table 15. Series-4-17-TR. Power dependence on total mirror transmission at optimal iodine flow rate.

$P_1$	$M_C$	$M_I$	$T_1, \%$	$T_2, \%$	$T_1 + T_2$	$W_1$	$W_t$	$W_{10}$	$\eta_{\text{chem,}}$
19.4	9.4	0.28 5	0.8	0.18	0.98	114	114	149	16.4
20.5	11	0.28 5	0.7	0.18	0.88	112	142	129	14.2

19.2	10.2	0.28	0.7	0.8	1.5	44.5	95	93	10.3
18.9	10.2	0.28 5	1.7	0.8	2.5	39	57	56	6.2
19.2	10.7	0.28	1.7	0.18	1.88	72	80	75	8.3
18.7	10.6	0.28	1.7	1.7	3.4	15.5	31	29	3.4
20.6	9.46	0.29 7	1.7	0.18	1.88	106	117	124	13.7



#### 4.8. Experiments with BHP molarity 4M and temperature $-10^{\circ}\text{C}$ .(series 4-10-12, 4-10-TR).

These two series were made during one experimental day. The BHP was prepared from 4390 ml of 37.5% wt  $\text{H}_2\text{O}_2$  (type 3), 1975g of 87% dry KOH, 1200g of distilled  $\text{H}_2\text{O}$ , 1800g of 99.2% wt.KCl. First of all 1200 g of water was added to 37.5%wt. $\text{H}_2\text{O}_2$ . After that dry KCl was dissolved in  $\text{H}_2\text{O}_2\text{-H}_2\text{O}$  at temperature more than  $0^{\circ}\text{C}$ . Then dry KOH was added to solution  $\text{H}_2\text{O}_2 + \text{H}_2\text{O} + \text{KCl}$ . During adding of KOH the temperature of solution was  $0^{\circ}\text{C} \div -7^{\circ}\text{C}$ . Then BHP was cooled to  $-10^{\circ}\text{C}$  and filtered from KCl particles through  $0.3 \times 0.3$  mm filter. The total weight of removed wet salt was 800g. But after that BHP contained suspension of salt nevertheless. The titration of BHP resulted in concentrations  $[\text{KOH}] = 3.8$  M,  $[\text{H}_2\text{O}_2](\text{total}) = 6.8$  M. After 4 hours of experiments (series 4-10-12, 4-10-TR) titration resulted in  $[\text{KOH}] = 3.6$  M,  $[\text{H}_2\text{O}_2] = 5.9$  M. Results of these series are presented in Tables 16 and Table 17.

Table 16.Series-4-10-12. Power dependence on iodine flow rate.

$P_1$	$M_C$	$M_I$	$T_1, \%$	$T_2, \%$	$T_1 + T_2$	$W_1$	$W_t$	$W_{10}$	$\eta_{\text{chem,}}$
22	10.9	0.31 2	0.8	0.18	0.98	104	127	116	12.8
20.6	9.1	0.27	0.8	0.18	0.98	107	131	144	15.9
22.4	9.8	0.21 4	0.8	0.18	0.98	70	86	88	9.7
22	9.2	0.25 6	0.8	0.18	0.98	87	107	116	12.8
24.1	9.56	0.35 6	0.8	0.18	0.98	79	96	101	11.1

The optimal iodine molar flow rate was found to be equal 0.28 mmole/s

Table 17. Series-4-10-TR. Power dependence on total mirror transmission at optimal iodine flow rate.

$P_1$	$M_C$	$M_I$	$T_1, \%$	$T_2, \%$	$T_1 + T_2$	$W_1$	$W_t$	$W_{10}$	$\eta_{\text{chem,}}$
20.6	9.1	0.27	0.8	0.18	0.98	107	131	144	15.9
22.1	10.1	0.30 2	0.7	0.18	0.88	98	123	122	13.5
21.4	9.4	0.29 5	1.7	0.18	1.88	88	97	103	11.4

21.3	9.4	0.28 3	0.7	0.8	1.5	47	100	106	11.8
22	9.4	0.28	1.7	1.7	3.4	8	16	17	1.9
20.6	9.46	0.29 7	1.7	0.18	1.88	106	117	123	13.7
21.5 5	9.14	0.29	1.7	0.8	2.5	43	64	70	7.7

#### 4.9. Experiments with BHP molarity 4M and temperature $-0^{\circ}\text{C}$ .(series 4-00-I2, 4-00-TR).

(The values presented in series Tables 18,19 differ from values presented in report3. A more accurate processing of dates was made).

These two series were made during one experimental day. The BHP was prepared from 3500 ml of 37.5% wt  $\text{H}_2\text{O}_2$  (type 3), 1545g of 87% dry KOH, 700g of distilled  $\text{H}_2\text{O}$ , 1800g of 99.2% wt.KCl. First of all 700 g of water was added to 37.5%wt. $\text{H}_2\text{O}_2$ . After that dry KCl was dissolved in  $\text{H}_2\text{O}_2$ - $\text{H}_2\text{O}$  at temperature more than  $0^{\circ}\text{C}$ . Then dry KOH was added to solution  $\text{H}_2\text{O}_2 + \text{H}_2\text{O} + \text{KCl}$ . During adding of KOH the temperature of solution was  $+1^{\circ}\text{C} \div -1^{\circ}\text{C}$ . Then BHP was fixed at  $+1^{\circ}\text{C} \div -1^{\circ}\text{C}$  and filtered from KCl particles through  $0.3 \times 0.3$  mm filter. The total weight of removed wet salt was 1300 g. But after that BHP contained suspension of salt nevertheless. The titration of BHP resulted in concentrations  $[\text{KOH}] = 4$  M,  $[\text{H}_2\text{O}_2](\text{total}) = 6.85$  M. After 2 hours of experiments (series 4-00-I2, 4-00-TR) titration resulted in  $[\text{KOH}] = 3.9$  M,  $[\text{H}_2\text{O}_2] = 4.65$  M. It was found that this BHP at  $0^{\circ}\text{C}$  was very unstable. Visually BHP was looking like mixture of bubbles with liquid. We explain big consumption of  $\text{H}_2\text{O}_2$  by strong BHP decomposition. Results of these series are presented in Tables 18 and Table 19.

Table 18. Series-4-00-I2. Power dependence on iodine flow rate.

$P_1$	$M_c$	$M_i$	$T_1, \%$	$T_2, \%$	$T_1 + T_2$	$W_1$	$W_t$	$W_{10}$	$\eta_{\text{chem}}$
25.2	11	0.22	0.8	0.18	0.98	107	132	120	13.2
25.3	9.5	0.28	0.8	0.18	0.98	120	147	155	17.1
25.5	10.4	0.25	0.8	0.18	0.98	108	132	127	14
25.1	9.6	0.36	0.8	0.18	0.98	84	103	107	11.8

The optimal iodine molar flow rate was found to be equal 0.28 mmole/s

Table 19. Series-4-00-TR. Power dependence on total mirror transmission at optimal iodine flow rate.

$P_1$	$M_c$	$M_i$	$T_1, \%$	$T_2, \%$	$T_1 + T_2$	$W_1$	$W_t$	$W_{10}$	$\eta_{\text{chem}}$
25.3	9.5	0.28	0.8	0.18	0.98	120	147	155	17.1
25	9.7	0.28	1.7	0.18	1.88	73	81	84	9.2
23	9.2	0.29	1.7	0.8	2.5	30	44	48	5.3
22	10	0.28	0.7	0.8	1.5	51	110	110	12.1
21.8	9.3	0.29	1.7	1.7	3.4	7.1	14. 3	15.4	1.7



## 5. Measurements of $O_2(^1\Delta)$ yield, $Cl_2$ utilization and $H_2O$ content.

5.1. Series JSOG-8M. The results presented in Table 20 were obtained during one experimental day. The BHP was prepared from 3134 ml of 50%wt  $H_2O_2$ , 1720g of  $H_2O$  and 2944g of 92% dry KOH. Firstly BHP temperature was fixed close to  $0^\circ C$ . After 3-d JSOG run BHP was cooled to  $-10^\circ C$  and after 6-th run BHP was cooled to  $-20^\circ C$ . At the start of experiments titration resulted in  $[KOH]=7.8M$ ,  $[H_2O_2](total)=9M$ . At the end of experiments  $[KOH]=7.4M$ ,  $[H_2O_2](total)=8.3 M$ . The duration of one JSOG run was approximately 20 s.

Table 20. Series JSOG-8M.

BHP t, $^\circ C$	$P_1$	$M_c$	$P_2$	$P_{H_2O}$	$P_{H_2O}/P_2$	U, %	Y
-2.1	21.4	9.5	2	0.26	0.132	>98	0.77
-2.1	20.5	8.9	1.62	0.21	0.128	>98	0.78
-3.9	21	9.4	2	0.19	0.094	>98	0.81
-10.5	19.9	10	1.91	0.14	0.074	>98	0.82
-10.6	21	9.53	1.98	0.12	0.062	>98	0.84
-23.5	17.9	9.7	1.55	0.08	0.053	>98	0.79
-22	20.2	9.7	1.78	0.055	0.031	>98	0.81
-19.5	22.1	10.3	1.84	0.068	0.037	>98	0.79

5.2. Series JSOG-6M. The results presented in Table 21 were obtained during one experimental day. The BHP was prepared from 2800 ml of 50%wt  $H_2O_2$ , 2378g of 92% dry KOH, 2034ml of  $H_2O$  and 900g of 92% KOH at  $0^\circ C$  in the same manner as in p.4.6. Firstly BHP temperature was fixed close to  $0^\circ C$ . At  $0^\circ C$  BHP didn't contain KCl particles with diameter more than 0.3 mm. After 3-d JSOG runs BHP was cooled to  $-10^\circ C$  and 323 g of wet salt were removed from BHP. After 5-th run BHP was cooled to  $-20^\circ C$  and additionally 130 g of wet salt were removed from BHP. At the start of experiments titration resulted in  $[KOH]=5.8 M$ ,  $[H_2O_2](total)=7.35M$ . At the end of experiments  $[KOH]=5.45M$ ,  $[H_2O_2](total)=6.3 M$ . The duration of one JSOG run was approximately 20 s. The suspension of salt was observed in BHP at all temperatures.

Table 21. Series JSOG-6M

BHP t, $^\circ C$	$P_1$	$M_c$	$P_2$	$P_{H_2O}$	$P_{H_2O}/P_2$	U, %	Y
0	23	9.1	1.85	0.27	0.14	>98	0.79
-2.4	22	9.5	1.77	0.21	0.12	>98	0.85
-1.6	18	7.2	1.56	0.28	0.18	>98	0.83

-11	21	9.8	1.88	0.15	0.078	>98	0.87
-14	20.5	9.9	1.77	0.13	0.072	>98	0.87
-21	21.2	9.9	1.66	0.06	0.036	96	0.78
-20	20	10	1.94	0.07	0.038	95	0.8
-23	21	10.6	1.72	0.06	0.035	96	0.78
			6				

5.2.Series JSOG-4M. The results presented in Table 22 were obtained during one experimental day. The BHP was prepared from 2480 ml of 50%wt  $H_2O_2$ , 1560g of 92% dry KOH, 2210 ml of  $H_2O$  and 1800 g of 92% KOH at  $0^\circ C$  in the same manner as in p.4.6. Firstly BHP temperature was fixed close to  $0^\circ C$ . At  $0^\circ$  1072g of wet salt were removed from BHP. After 3-d JSOG run BHP was cooled to  $-10^\circ C$  and additionally 614 g of wet salt were removed from BHP. After 5-th run BHP was cooled to  $-17^\circ C$  and additionally 37 g of wet salt were removed from BHP. At the start of experiments titration resulted in  $[KOH]=4$  M,  $[H_2O_2](total)=6.75$ M. At the end of experiments  $[KOH]=3.8$ M,  $[H_2O_2](total)=5.8$  M. The duration of one JSOG run was approximately 20 s. The suspension of salt was observed in BHP at all temperatures.

Table 22.Series JSOG-4M.

BHP t, $^\circ C$	P <sub>1</sub>	M <sub>c</sub>	P <sub>2</sub>	P <sub>H<sub>2</sub>O</sub>	P <sub>H<sub>2</sub>O</sub> /P <sub>2</sub>	U,%	Y
1.5	22	10.5	2.3	0.37	0.16	96	0.76
-2	23	10.1	2.18	0.33	0.15	96	0.78
-11	22	9.2	1.78	0.15	0.087	93	0.85
-10.7	23	10.4	2	0.16	0.082	94	0.81
-11	22	10.8	2.04	0.19	0.095	>98	0.76
-17.5	21	10	1.86	0.10	0.055	90	0.82
-17	19	10.8	1.94	0.11	0.057	88	0.72

## 6. Discussion of experimental results.

6.1. Water vapor content. The summary of measurements of water vapor content in series JSOG-8,6,4 are presented in fig.5,6

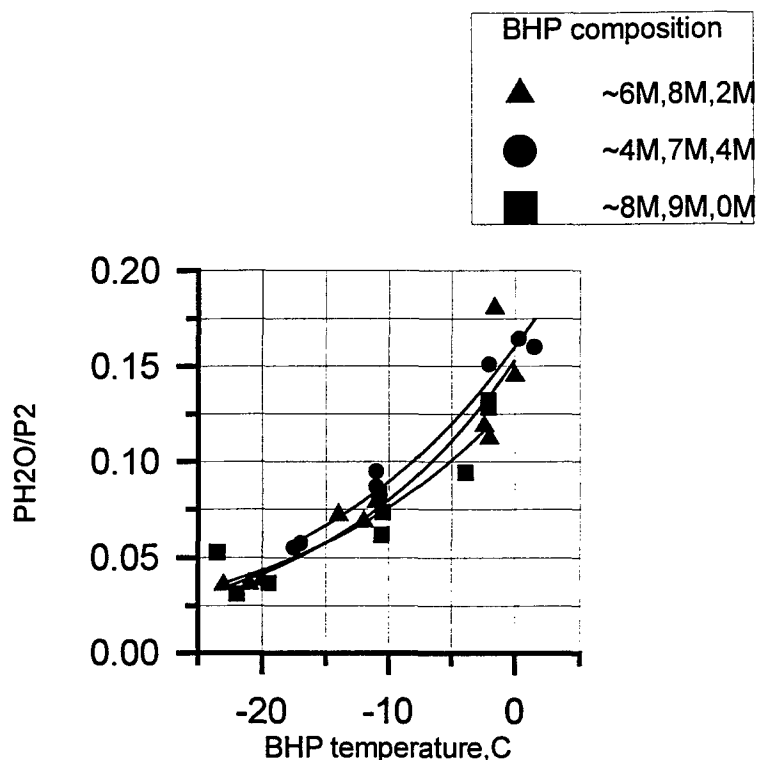


Fig.5 The dependence of relative water vapor content at the exit of JSOG

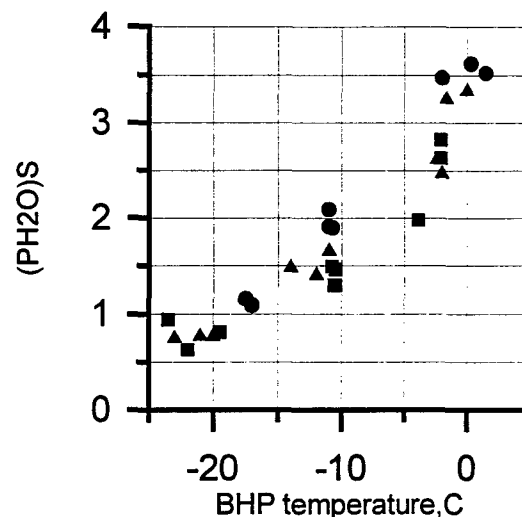


Fig.6. Estimated saturated water vapor pressure

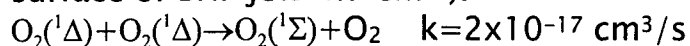
The water vapor content depends mainly on BHP temperature rather than its molarity. The water vapor content depends on the saturated water vapor pressure inside JSOG and number of droplets carried out from JSOG. In the present work the droplets mass flow rate from JSOG was not measured. The absolute water vapor pressure ( $P_{H_2O}$ )<sub>S</sub> inside JSOG is a more invariant value in the absence of droplets in intermediate chamber 4. ( $P_{H_2O}$ )<sub>S</sub> can be calculated as  $(P_{H_2O})_S = P_{H_2O} \cdot P_1 / P_2$  (Fig.6). The obtained values ( $P_{H_2O}$ )<sub>S</sub> is a reasonable value of water vapor pressure over BHP. For BHP temperatures -20°C, -10°C, 0°C the saturated pressure ( $P_{H_2O}$ )<sub>S</sub> equals to 0.7 torr, 1.5 torr and 3.5 torr respectively. The regular error of measurements  $P_{H_2O}$  is due to quenching of  $O_2(^1\Sigma)$  by  $O_2$  (no primary and secondary nitrogen). At total pressure  $P_2 = 3$  torr the regular error of water vapor measurements is equal to  $P_2 k_{O_2} / k_{H_2O} \approx 2 \times 10^{-5}$  torr, where  $k_{O_2} = 4 \times 10^{-17}$  cm<sup>3</sup>/s,  $k_{H_2O} = 6.7 \times 10^{-12}$  cm<sup>3</sup>/s the rate constants of  $O_2(^1\Sigma)$  quenching by  $O_2$  and  $H_2O$  accordingly [4]. This error much less error of measurements.

In the case of COIL operation with adding of 20 mmole/s of primary nitrogen to  $O_2$  flow the water vapor in front of iodine mixer can be find as  $P_{H_2O} \approx P_2 \cdot (P_{H_2O})_S / P_1 \cdot (M_c / (M_c + M_{Np}))$ , where  $P_2$ —total pressure in intermediate chamber,  $P_1$ —pressure inside JSOG. For typical COIL tests  $P_1 = 20$  torr,  $P_2 = 11$  torr and  $M_c / (M_c + M_{Np}) = 0.33$ . Thus the estimated partial water vapor pressure in front



of iodine mixer was 0.13 torr, 0.27 torr and 0.64 torr for BHP temperatures - 20°C, -10°C, 0°C respectively during COIL operation.

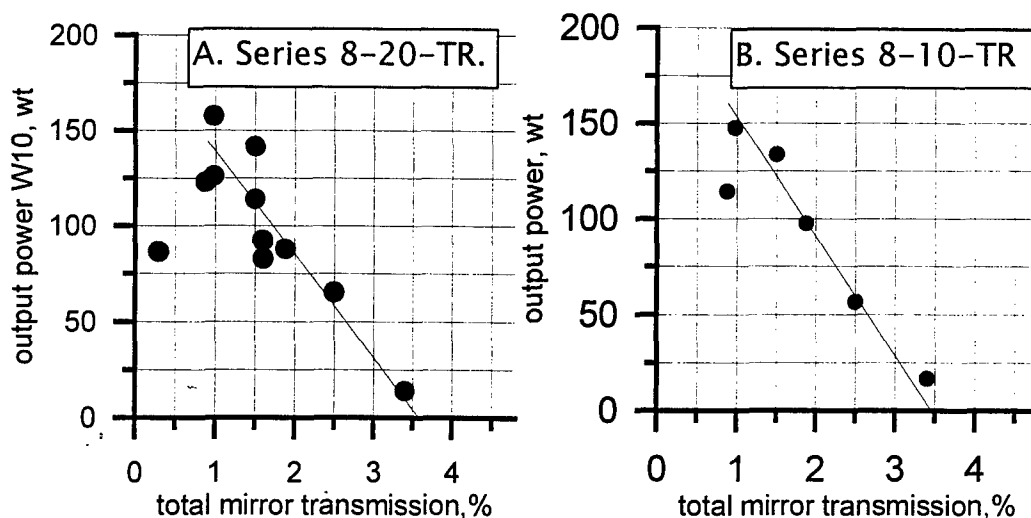
6.2.  $O_2(^1\Delta)$  yield didn't depend on BHP composition and its temperatures in the limits of error. From the first point of view 80%  $O_2(^1\Delta)$  yield is unexpectedly high. Let's estimate possible losses of  $O_2(^1\Delta)$  in reaction zone of JSOG ( $O_2(^1\Delta)$  losses in intermediate chamber much less). The gas residence time is equal to  $10\text{cm}/1400(\text{cm/s})=7.1\text{ ms}$ . The main losses of  $O_2(^1\Delta)$  are due to reactions ( $O_2(^1\Delta)$  losses on the BHP surface much less at flight time 7ms and specific surface of BHP jets  $4.7\text{ cm}^{-1}$ ).

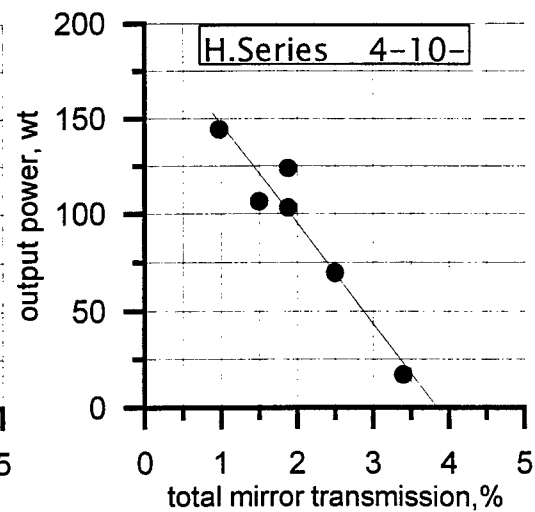
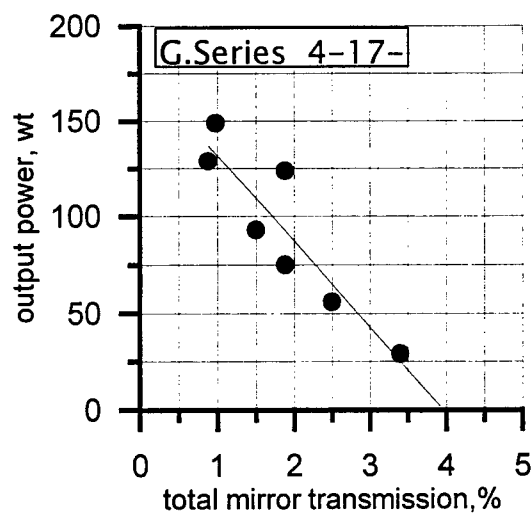
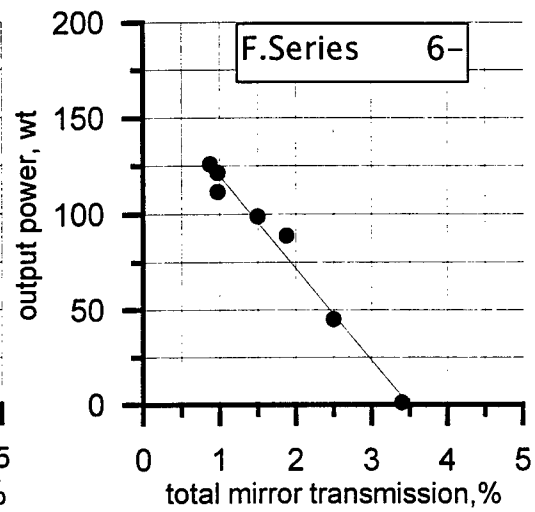
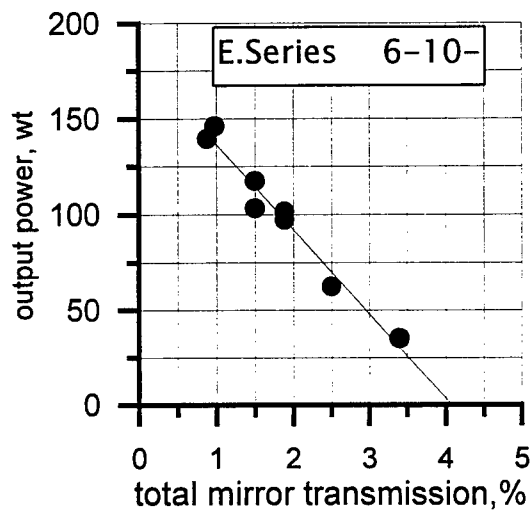
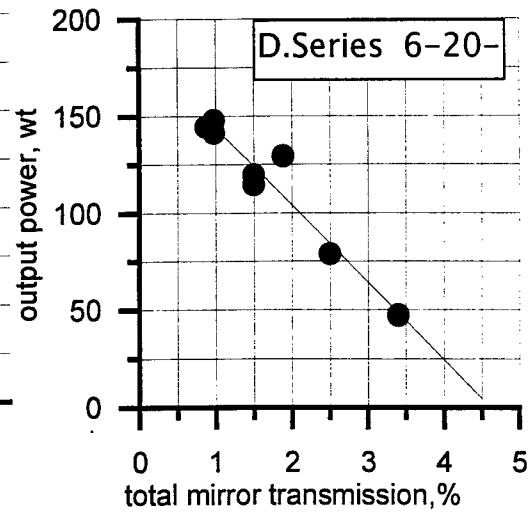
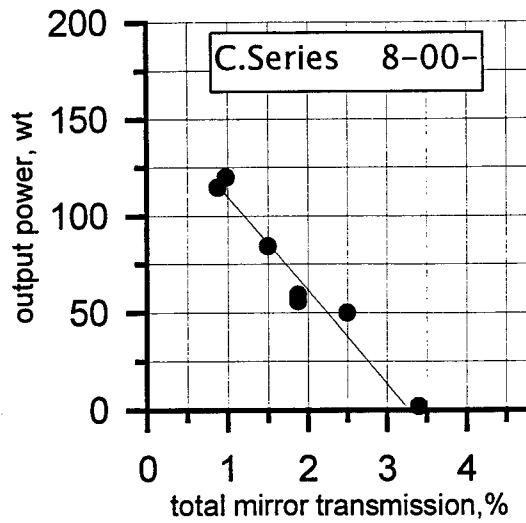


The estimation of maximum losses is  $\Delta Y \approx 20\text{ torr} \times 3.3 \times 10^{16}(\text{cm}^{-3}\text{torr}^{-1}) \times (2 \times 10^{-17} + 3.4 \times 10^{-17} + 0.68 \times 10^{-17}) \times 0.0071\text{s} = 0.28$ . It is very overestimated  $O_2(^1\Delta)$  losses in JSOG. Thus 80%  $O_2(^1\Delta)$  yield seems to us reasonable value.

6.3 Chlorine utilization for BHP molarity 8M and 6M close to 100%. The chlorine utilization 90÷95% is in agreement with our previous measurements for BHP with molarity 4M÷6M [5]. These value of utilization results in estimation of average rate of chlorine absorption by jets 90 cm/s as minimal.

6.4 The optimal iodine flow rate depends slightly on BHP composition: the optimal iodine molar flow rate less for lower BHP molarity. We have not exhaustive explanation of this fact now. The dependence of total output power  $W_{10}$  on total mirror transmission for all BHP temperatures and molarities at optimal gas flow conditions are presented in Fig.7 (A-I).





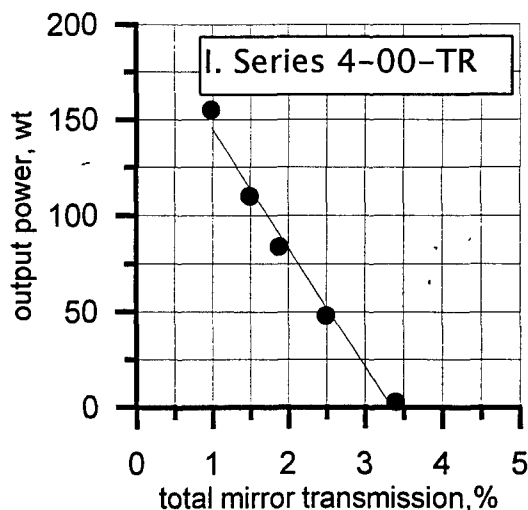


Fig.7

The saturation curve in series 8-20-TR was obtained with all possible sets of mirrors. Let's estimate nonresonant radiation losses and small signal gain (SSG) assuming that nonresonant losses were the same for all sets of mirrors. From curve in series 8-20-TR one obtains that optimal total mirror transmission is  $T_{opt}=T_1+T_2\approx 1\%$  and threshold total transmission  $T_{th}=3.6\%$ . The SSG  $g_{sg}$ , optimal transmission, nonresonant losses  $\alpha$  are connected (Rigrod [6]):

$$T_{opt} = \sqrt{2l_a g_{sg} \alpha} - \alpha, \text{ where } 2l_a g_{sg} = T_{th} + \alpha, l_a = 5 \text{ cm gain length.}$$

From these two equations one obtains estimation  $\alpha \approx 0.55\%$ ,  $g_{sg} \approx 4.15 \times 10^{-3} \text{ cm}^{-1}$ . The maximum extraction efficiency of laser cavity at total mirror transmission  $T_{opt}$  is equal to

$$\eta_{ext} = \left( 1 - \sqrt{\frac{\alpha}{2l_a g_{sg}}} \right)^2 = 0.4. \text{ For initial } O_2(^1\Delta) \text{ yield } 80\%, \text{ threshold } O_2(^1\Delta) \text{ content } 8\%$$

(gas temperature in laser cavity 220K),  $O_2(^1\Delta)$  losses 0.07 for  $I_2$  dissociation one obtains maximum total chemical efficiency of present COIL  $\eta_c = 0.4(0.8 - 0.08 - 0.07) = 26\%$ . The maximum experimental efficiency 18% much less than estimated. We explain this discrepancy with existing of boundary layers in presented small scale COIL where small signal gain much less than in the kernel of gas flow in laser cavity.

The dependence of threshold total mirror transmission and SSG  $g_{sg} = (T_{th} + \alpha)/2l_a$  on BHP temperature and composition (at optimal gas flow conditions) are presented in Fig.8.

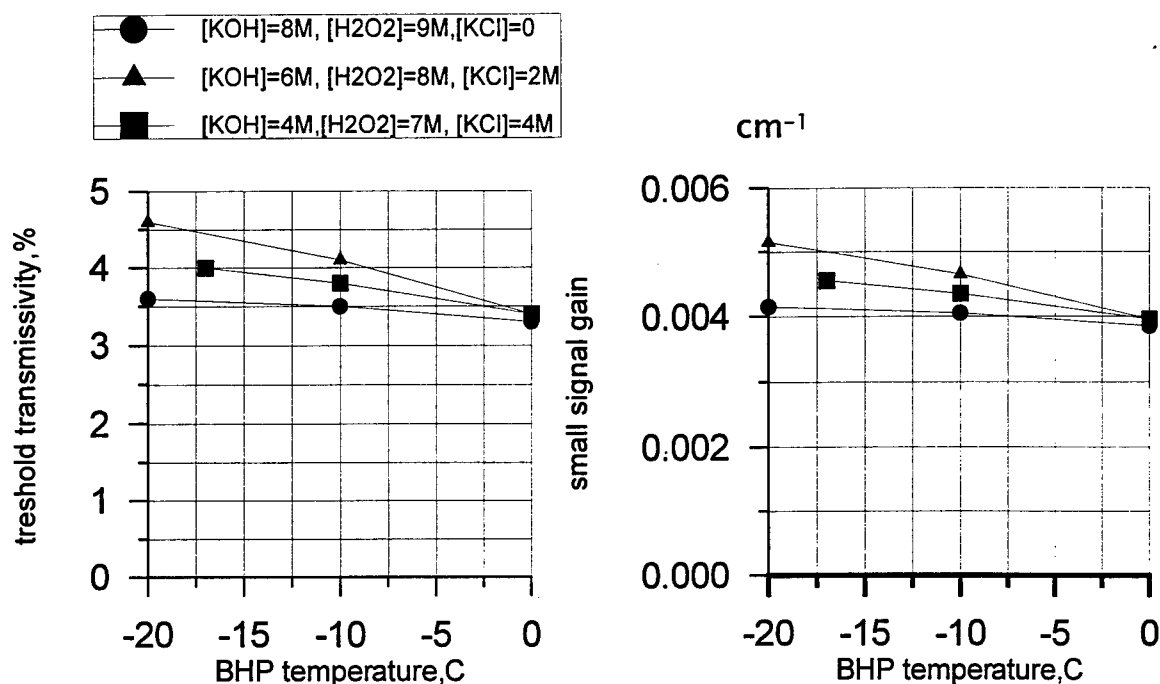


Fig.8.

SSG decreases with increasing of BHP temperature and SSG is the highest for BHP with molarity 6M and 0.3 mmole/s iodine flow rate. The decreasing of small signal gain with increasing of BHP temperature we explain with increasing of water vapor content in gas flow. Increasing of water vapor content results in increasing quenching of  $O_2(^1\Sigma)$ . The  $O_2(^1\Sigma)$  molecules responsible for the first step of iodine dissociation  $O_2(^1\Sigma) + I_2 \rightarrow O_2 + 2I$ . On the other hand the rates constant of relaxation of vibrationally excited  $I_2$  molecules by  $H_2O$  and  $N_2$ ,  $O_2$  are very close [7] but  $[H_2O] \ll [N_2], [O_2]$ . The strong effect of small amount of water on SSG is evidence that initial dissociation of  $I_2$  through  $O_2(^1\Delta)$  ( $I_2 + O_2(^1\Delta) \rightarrow I_2(v) + O_2$ ,  $I_2(v) + O_2(^1\Delta) \rightarrow 2I + O_2$ ) is negligible in comparison with  $O_2(^1\Sigma) + I_2 \rightarrow O_2 + 2I$ . Thus the main reason of decreasing of small signal with increasing BHP temperature is the increasing of  $O_2(^1\Sigma)$  quenching by  $H_2O$  molecules.

The maximum power  $W_{10}$  for all BHP was achieved with mirrors  $T_1=0.8\%$ ,  $T_2=0.18\%$  (Fig.9).

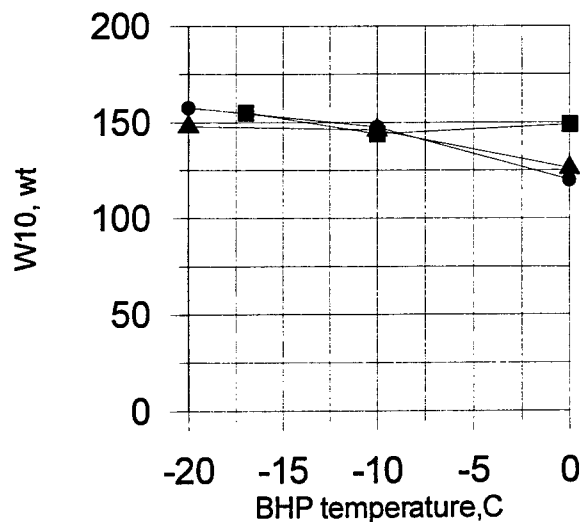


Fig.9.

The decreasing of output power with increasing of BHP temperature is due to decreasing small signal gain rather than direct  $O_2(^1\Delta)$  losses in reactions  $I^* + H_2O \rightarrow I + H_2O$ ,  $O_2(^1\Delta) + I \rightarrow O_2 + I^*$ . It seems to us the unexpected high power  $W_{10}$  for BHP 4M at 0C is due to accidental summation of all possible errors of measurements ( $W_1$ ,  $M_C$ ).

## 7. Summary and conclusions.

The output power of present supersonic COIL driven by Jet SOG slowly depends on BHP molarity from 8M (KOH) to 4M(KOH). The Jet SOG stable operates with BHP contained suspension of KCl salt. In all tests with 6M and 4M BHP was completely saturated with salt. In the case of BHP recirculation the big salt particles must be removed. The size of KCL particles must be less than jet nozzle diameter. It is possible to use mixtures KOH+NaOH+LiOH as base in BHP to avoid salt particles formation.

The small signal gain and maximum achieved power of present COIL decrease with increase BHP temperature. The quenching of  $O_2(^1\Sigma)$  by  $H_2O$  is the main reason of SSG decreasing rather than quenching of vibrationally excited  $I_2$  by  $H_2O$ . The quenching of  $O_2(^1\Sigma)$  results in slower initial rate of iodine dissociation and lower gain.

Let's consider continuous COIL operation with BHP at initial molarity 8M. From presented results COIL can operate down to 4M of BHP molarity without dropping of output power. 1 liter of BHP can generate  $(8-4)/2=2$  mole of oxygen. The total energy emitted by COIL with chemical efficiency 18% will be equal to  $E=90.6 \text{ KJ} \times 0.18 \times 2 = 65 \text{ KJ}$ . Let's estimate mass of all needed chemicals do emit 65 kJ output energy:  $Cl_2$ -1 mole-71g, BHP-1liter=1440g,  $N_2=3$  moles=84g,  $I_2$ -0.06 mole =15g. The total mass of chemicals  $M=1610\text{g}$ . The specific output energy will be  $\varepsilon=65000\text{J}/1610=40\text{Joule per gram}$ . In the case of 35% total chemical efficiency  $\varepsilon=78 \text{ Joule per gram}$ . This specific energy is much less than for HF-laser but comparable with gasdynamical  $CO_2$ -laser.

## 8. Description of proposed Phase 2

### 8.1. The design of JSOG and COIL for 0.10 mole/sec chlorine flow rate with He diluent.

Samara supersonic COIL set-up ( the chlorine flow rate of which needed to increase to 0.10 mole/sec (with He diluent)) consists of the next main units: BHP preparing and delivering system, Cooling system, JSOG, Nozzle block, Chlorine feeding system, Iodine generator, Optical cavity, Vacuum duct, Vacuum pumping system, Liquid nitrogen trap.

The old units which may be used for COIL at 100 mmole/s: BHP preparing system and BHP receiver, the vacuum duct and vacuum pump for preliminary pumping of the vacuum receiver, the most part of the chlorine feeding system, optical cavity, the liquid nitrogen trap, BHP recirculation system.

The units which must be modernized or created all over again: 1) the cooling system with more cooling power, 2) JSOG, 3) the supersonic nozzle

system, 4) some part of the chlorine feeding system (the gas chlorine receiver with a moving plastic cover for supporting constant chlorine flow rate), 5) the vacuum receiver, 6) the iodine generator, 7) BHP feeding system, 8) BHP recirculation system.

**New cooling system.** The cooling system will be created on the base of the compressor CAJ9480 with electrical power 1 kWt and using R 22 for reaching temperature  $-30\text{ }^{\circ}\text{C}$  (the project of this system exists). The cooling power of refrigerator will be 1.8 kWt. The price of this system creation (including purchase of compressor) is about 2,500\$.

**Chlorine feeding system.** For supporting constant chlorine flow rate during COIL operation one suppose to use the plastic envelope with the perforated feeding tube inside and volume 25 liters. The safety of operation is the most important. For this purpose the plastic envelope will be placed inside polyethylene tube. The envelope will be fulfilled with chlorine at atmospheric pressure. The chlorine molar flow rate will be metered by calibrated choke orifice.

**Iodine generator.** Some modernization is needed for iodine generator. We must increase the carrier buffer gas duct conductivity, provide pre-heating the carrier buffer gas and to rise the iodine duct temperature. The power needed to evaporate 3 mmole/sec of iodine (3% from chlorine flow rate) is 120 Wt. We need to manufacture new cell for iodine and absorption-spectroscopy tube with  $1\div 2\text{ cm}$  pathway for light beam at 500 nm.

**Vacuum system.** The conductivity of supersonic nozzle increases sharply when primary buffer gas He at dilution 1:3 is used. Our tests show that existing duct provides gas conductivity 1100 liters/sec and support supersonic regime for nozzle with throat  $5\cdot 0.8 = 4\text{ cm}^2$  during 2.4 seconds. One suggests to increase the total vacuum receiver volume to  $15\text{ m}^3$  (old receiver volume is  $4\text{ m}^3$ ). Such receiver will provide supersonic regime during 9 sec. This time is enough for reaching stationary COIL operation. One suggests to use two additional receivers with  $5.5\text{ m}^3$  volume each manufactured from Al. The estimated cost of additional tanks is about 20,000\$. The cost includes calculation the strength of tank, creation of the working drawings, buying of Al metal for manufacturing receivers, manufacturing, transport, installation and vacuum tests.

**BHP recirculation.** BHP recirculation system we may buy with aid Phillips Laboratory. This system simplifies adjustment BHP and chlorine flow rates and prevents sometimes the foam flying away to duct at switching off jet generator. BHP recirculation system will give us possibility to operate in continuous regime and change regime parameters during COIL operation. The suitable BHP pumps are gear pumps of 312 or 312-MC series which are product of LIQUIFLO corporation (140 Mount Bethel Road Warren, New Jersey 07060, (201) 754-1336, fax (201) 754-3280). The cost of this gear pump is approximately 2000\$.

**Project JSOG for 0.10 mole/sec chlorine flow rate.** There are several possible JSOG designs for 100 mmole/s chlorine flow rate to obtain high  $\text{O}_2(^1\Delta)$  yield ( $>60\%$ ) and  $\text{Cl}_2$  utilization ( $>90\%$ ). The JSOG working point is determined by jet's specific surface, base molarity, gas and liquid velocities, gas pressure, distance between gas inlet and outlet in reaction zone, BHP temperature and it's flow regime in nozzles. We plan to create the compact JSOG using our experience of the tests of different JSOG. In Table the published and unpublished results of JSOG tests are presented.

[KOH]	L	d	N	S	$\sigma$	$U_j$	P	$m_c$	$U_g$	B:Cl <sub>2</sub>	$U_c$	Y	Ref.
3	10	0.3	85	1.13	7.1	14	60	8.9	27	0:1	>9 0	>6 0	[1]
4	10	0.5	45	1.13	6.25	12	59	4.9	15	0:1	93	59	[3]
4	10	0.5	45	1.13	6.25	12	104	4.9	19	1.2(Ar):1	90	68	[3]
4	15	0.8 0.7	20 86	5.7	4.2	7.4	89	3.7	20	1.6(He): 1	93	80	no
6	10	0.8	86	5.7	3.8	5.4	31	3.2	19	0:1	90	70	no
8	10	0.8	106	5.7	4.67	4.5	20	1.8	16	0:1	>9 8	80	prese nt.
7.2	21.7	-	-	202	5.06	10	159	4.5	31	5(He):1	93	61	[8]

[KOH]-BHP molarity mole/l, L (cm)-length of reaction zone in JSOG, d (mm)-jet nozzle diameter,  $\sigma(\text{cm}^{-1})=\pi d^2 N/S$ -estimated specific surface of gas-liquid surface, N-number of nozzles, S( $\text{cm}^2$ )-cross section of reaction zone,  $U_j(\text{m/s})$ -average BHP velocity in nozzle, P-total pressure in reaction zone,  $m_c(\text{mmole}/\text{cm}^2/\text{s})=\rho V$ -molar flow density of chlorine inside JSOG,  $U_g(\text{m/s})$ -average gas velocity, B:Cl<sub>2</sub>-dilution of chlorine with buffer gas,  $U_c(\%)$ -chlorine utilization, Y(%)-O<sub>2</sub>(<sup>1</sup> $\Delta$ ) yield, Ref.-reference.

In general the search of optimal JSOG configuration and parameters for 100 mmole/s of chlorine is a subject of investigation. The main principle of designing is scaleable JSOG. It means that cross section of gas flow in JSOG have to be made close to the cross section of gas flow in laser cavity. In this case the volume between JSOG and COIL will be minimal.

The sketch of Verty-JSOG is shown in Fig.1. The maximum chlorine flow rate through this JSOG is 100mmole/s. The cross section of reaction zone consists of two parallel reaction zones with total cross section 34x50 mm<sup>2</sup>. The total working cross section 26x50 mm<sup>2</sup> (the detail sketch of JSOG-100 was presented in report2.). The length of reaction zone is 17 cm. The maximum density of chlorine flow rate is equal to 7.7 mmole/cm<sup>2</sup>/s at initial chlorine pressure 50 torr and gas velocity 24.3 m/s. The results presented in Table show that it is possible to achieve 7.7 mmole/cm<sup>2</sup>/s specific flow rate with generation of oxygen with high O<sub>2</sub>(<sup>1</sup> $\Delta$ ) yield and high chlorine utilization. The gas residence time is equal to  $17/2430=0.007$  sec. According to measurements of chlorine utilization the rate of chlorine absorption is 90 cm/s at 8M BHP. The specific surface  $\sigma=\ln(20)/90/0.007=4.7\text{ cm}^{-1}$  is needed to achieve 95% of chlorine utilization. But it is necessary to avoid strong BHP depletion on the surface of jets. The estimated jet's velocity 10 m/sec and BHP molarity  $-(6\div 8)$  mole/l are needed to avoid depletion. The estimated jet nozzle diameter 0.7 mm made in 0.5 mm are needed to achieve 10 m/s jet velocity at atmospheric pressure. The estimated total number of nozzles is 300. It is expected that Verty-JSOG will be more stable and will operate without carryout of BHP droplets.

The cost of JSOG +iodine system +chlorine feeding line modification approximately 6,5000\$.

The cost of the new SCOIL+JSOG+vacuum receivers + recirculation is estimated about 30,000\$.

## 8.2. The proposed experiments

The experiments with iodine injection into boundary layers in the throat region of the small-scale nozzles for determination of optimal conditions of COIL operation and gain shall be done at BHP composition (8÷7M), BHP temperature (-20°C). The next parameters shall be varied:

plenum oxygen pressure- 5 torr in existing set-up and 50 torr upgrade set-up  
penetration (secondary buffer gas flow rate)-optimization  
iodine concentration-optimization

Mirror reflectivities shall be changed for achievement of the highest output power and the determination of the gain at the optimal gas flow conditions.. Nitrogen as primary and secondary buffer gases is used only.

The experiments with mixing of co-flowing trans-sonic oxygen jet at  $M \approx 1$  (stagnation oxygen pressure 20torr) and supersonic  $N_2 + I_2$  jets at  $M \geq 3$  shall be done. Three parameters shall be varied: static pressure in the mixing duct (4,6,8,10 torr), iodine molar flow rate and distance between nozzle and optical axis. It is necessary to determine the width of the mixing zone and the exit nozzle width for  $N_2 + I_2$  jets in real COIL.

The tests of up-graded Verti-Jet SOG set-up shall involve the determination of singlet oxygen yield, chlorine utilization, water vapor pressure for chlorine molar flow rate 40,50,60,70,80,90,100 mmoles/s.

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